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Analytical Methods for Fire Safety Design

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ABSTRACT

The ability to predict aspects of fire and its impact on a building's structure, contents and people is discussed in terms of its application to safety design. It is presented from the perspective of how research has addressed the prediction of fire phenomena. A review of the state of the art on the capability for predicting the fire, its impact and response, is given. Examples are cited to illustrate the scope and accuracy of predictive methods and how they are being incorporated into some codes and standards.

Keywords: buildings; deterministic models; fire growth; people; review; structures

1. INTRODUCTION

By analytical methods for design, we mean the ability to perform calculations to assess the correctness of the design in terms of scientific principles. Once a design is conceived, we can use an analytical method to select the size, shape and nature of its materials and component parts. In the design of a complex system, it is usually not possible to have a method to predict all the interactions of the component parts. But by having an understanding of the system in terms of parameters -- properties and variables -- consistent with requirements of the analytical methods, complex systems can be

designed. This understanding allows us to break the problem into tractable pieces, whose solutions in the end provide the system design. As we learn more about the system, we can integrate the analysis to couple more and more of its elements together, or we can justify single-element approaches with more certainty.

Fire itself is a complex physical and chemical system so that the inclusion of its effect on structure and people make the situation more difficult to address. This is the realm of fire safety engineering and its application to fire safety design. It has only been over the last twenty-five years that a more quantitative understanding of fire and its impact has led to analytical methods for its prediction. It is therefore not surprising that the current prevailing design practice is not based on analytical methods. The current practice of fire safety design is based on meeting specific requirements in building codes and regulations that do not necessarily require any scientific analysis to achieve. The requirements are expressed for specific components of the system, and the methods for evaluating the performance of the component are given in terms of standards and test methods. For the most part, performance rankings by a specific test have been established by consensus and are applied to indicate implied performance in a particular design application or use; and in other cases, specifications are given without any scientific justification for the specific system under consideration. For example, the requirement that a wall lining material in a corridor must have a rating of less than 75 by a specific flammability test is an expression of performance. For an analytical method to be applicable, an alternative statement for the performance must be developed such as: the

material must not allow sustained flamespread in the specific corridor in a given time for a given ignition intensity. The exact values of the performance parameters are not important here, but they must be given in scientific terms. Of course the numeric values do become important when we wish to establish levels of equivalent performance with current notions of safety.

Therefore, the ability to assess the applicability of analytical methods for fire safety design depends on two factors. The first is the adequacy of the knowledge base to allow suitable and sufficiently accurate predictions. The second is the ease of recognizing the relationship between predictive capabilities, and the practices and issues that arise in applying fire safety codes and standards. This discussion will address the first factor in some detail, and attempt to give some examples which illustrate the second factor.

The process of developing the knowledge-base for fire has emerged from the agenda set by the research community. This agenda has been determined by a desire to understand all aspects of fire and its effects. Over the last fifteen years, this research has been oriented to the issues of fire growth in buildings. Fifteen years ago our knowledge was very sparse, so that a discussion on the prospect of using scientific analysis in fire safety design would have been premature. The ability to predict aspects of fire had to first gain credibility among scientists. In 1959, the International Symposium on the Use of Models in Fire Research was held [1]. Its focus was on fundamental knowledge and not its use, but the papers presented demonstrated the feasibility of fire prediction and quantification. In the mid-70's the

term "fire modeling" was coined to describe the various methods, mainly computer models, to predict the development of fire in a room. A review of compartment fire modeling, its nature, accuracies, and needs, was given by this author in 1984 [2]. In 1986, Emmons [3] reviewed the needs of "fire science" in terms of research needs, but with a view to solving practical problems. In this review, he cites 141 references which give some support to an emerging ordered-set of information -- a science of fire. A recent book, intended for educational purposes, by Drysdale [4] on ways to compute aspects of fire is a further demonstration of progress in the development of the knowledge base. The demand to assimilate this knowledge has been high. I believe Drysdale's book is now in its third printing. Several years ago I saw the new Japanese Fire Protection Handbook. It was very different from its previous editions because the first few hundred pages dealt with the science of fire and quantitative methods. Those sections reminded me more of the handbooks available to other engineering professions. It is noteworthy that in the USA, the Society of Fire Protection Engineers is now attempting to develop a handbook that will contain much new information from research. Thus, we see an evolution of the development of fire knowledge of sufficient scope and depth to now allow its orderly description for practitioners to learn and use. This is a significant milestone, but recognize that it has taken 15 to 25 years to achieve. Moreover, the depth of knowledge in particular areas is shallow and in some cases we have holes. Also, prediction capability on fundamental aspects of fire research do not always yield analytical tools for design.

2. ANALYTICAL APPROACH TO FIRE PREDICTION

Here I use the term analytical methods to mean any technique that will allow quantitative predictions. The technique could involve approximate or exact mathematical solutions, numerical solutions using computers, or analog and scaling techniques. Often scaling techniques have allowed formulas which have a wide range of applicability to be developed from experimental data.

2.1 Discrete Phenomena

Part of the progress made in fire prediction has been the ability to identify important features of the fire processes. This has come about due to experimental observations, conceptualization into a defined element for study, and then the development into a validated predictive result. For example, in a room fire, we identify the fire plume, a ceiling jet, a hot upper layer and flows at vents. Features associated with these elements have been studied and predictive prescriptions developed. In many cases, correlations have been developed from experimental data so that algebraic formulas comprise the nature of the results. Examples of reports which describe computational techniques for discrete phenomena have been given by Lawson and Quintiere [5], and Nelson [6].

2.2 Systems

Typically a fire problem will involve many processes, and it could be viewed as a set of interacting discrete elements. The degree to which we

couple these elements depends on our knowledge and understanding of them. For example, the evacuation of people in a fire will be affected by the fire conditions. Thus a complete analytical method for evacuation should take the relevant fire conditions into account. The temperature in a beam heated by a fire will affect its structural properties and determine the likelihood of failure. The beam temperature arises from the thermal state of the exposing fire, and all of this depends on the conservation of energy.

A particular approach to predicting fire conditions in compartments has been to mathematically couple together regions of distinct physical character. This relies on the application of the conservation laws, assumptions of the property distributions within the regions, and the predictive ability to describe the transfer of mass and energy at the boundaries of the regions. This has come to be called "zone modeling". The solution of this system mainly involves the solution of nonlinear algebraic and ordinary differential equations in time. The solution to partial differential equations could also arise. Thus, a small (PC) to medium-sized (mini) computer is necessary in its solution.

2.3 Exact Solution of the Basic Laws

It is possible to write the governing equations, based on mass, momentum and energy conservation for reacting fluid systems. In principle, their solution achieved by numerical methods on computers can lead to a complete description of the variables over space and time. However models need to be assumed for turbulence and for chemical reaction so that even these solutions

based on the exact differential equations are approximations. The models for turbulence and chemistry come from applications other than fire, so questions of their appropriateness are still not resolved. But a careful application of this approach to fire problems can lead to proper results, and this has been demonstrated in a number of applications. Fire researchers have come to call this approach "field modeling".

2.4 Scale Models

The analytical methods we are discussing are mathematical in nature. But we could utilize scaling techniques based on the laws of physics to develop physical scale models to generate quantitative information for fire safety design. This has its counterpart in wind tunnel testing of aircraft. For example, it has been demonstrated that the thermal and flow conditions in rooms adjoining the fire room can be reasonably predicted in full scale systems by using scale models [7,8].

3. STATE OF THE ART FOR DESIGN

I would like to review the capabilities for making predictions for various aspects of fire, its development and interactions as they relate to design. Where available, examples of their use in standards will be given.

3.1 Fire Source

No general predictive method exists for the generation rate of fuel mass, energy and combustion products for materials and products that make up the contents of buildings. But for many design applications, the initial fire source conditions might be specified in terms of a plausible or maximum credible fire condition for the problem under investigation. A suitable database of information on fuel packages, or a means to obtain the information must then be available. This is possible by measuring the combustion product concentrations in a collection hood above the freely burning fuel package [9]. Many research laboratories have such devices so that examples of results can be found in the literature.

For simple solid fuel systems, namely flat surfaces, burning rate theories and correlations exist to predict the steady rate of mass loss. From collection hood apparatuses, energy and combustion product yield data can be generated on a per unit mass loss basis [10]. The availability of these data provide a way to estimate steady generation rates for simple systems of arbitrary size.

The ability to predict ignition and flame spread only applies to flat solid fuels also, and requires particular data for the material. For example, these models use the concept of an ignition temperature so it must be appropriately determined for the material. A practical measurement technique to estimate such properties is available [11].

From a hazard point of view, it is useful to know the flame height. This can be computed with good accuracy for design purposes from correlations that depend only on the energy release rate of the fire and the equivalent diameter of the fuel base [12]. The maximum velocity and temperature distributions along the centerline of the fire and its noncombusting plume can be estimated in terms of the same variables required for flame height [13]. This appears to be successful over an extensive range of scales comparable with normal design needs.

The inability to completely predict the radiation heat transfer from flames in terms of practically measured properties limits models for burning rate and spread at relevant scales of interest. However we do have some knowledge of the range of radiant heating in some situations which can prove useful in design estimates. Except for distances very close to the flame, the radiant heating of the surroundings by the flame can be computed with good accuracy provided the fraction of energy radiated is known. This quantity is available in the literature for some materials and tends to vary from 15 to 50%. It can be deduced from the free burn fuel package experiments.

3.2 Effect of Surroundings on the Fire

We know that the temperature and oxygen concentration of the atmosphere around the fire affect the burning and mass loss rate of the (solid) fuel. Also radiant heat flux from the surroundings is a factor along with any imposed wind conditions. Models for steady burning and flame spread for simple configurations provide a means to quantitatively estimate the magnitude

of these environmental effects. In some cases, algebraic expressions exist for the steady simple configurations. For the more general case of unsteady burning of a complex fuel package, no generally acceptable procedure has been developed. Sensible extrapolation of the mathematical relationships governing simple fuel configurations is certainly viable and reasonable for design use. Again property data for the fuel package is needed; a key property is the effective heat of gasification. In general, this property is time-dependent, and no standard test exists for its determination. But time-averaged values have been determined for a number of materials [10]. The heat of gasification is essential in determining the rate of gaseous fuel generation from the available fuel packages as their decompositions are augmented and initiated by heat transfer from the environment. This is a feedback process that the fire lives and dies by. As the fire grows, environmental oxygen decreases and the environmental heat transfer increases. If the fuel package is totally immersed in an atmosphere of decreasing oxygen, flaming combustion will cease at some critical value of oxygen concentration. This value is not unique, but some data and crude methods exist for its estimation. Ten per cent or less is a nominal rule of thumb.

In addition to the effect of the fire environment on the fuel generation rate, it is well known that the products of combustion change with the available oxygen supply rate. We can think of this as two streams: the fuel stream caused by heat transfer to the solid fuel surface, and the oxygen stream entrained into the fire plume. The entrainment rate can be calculated [12,13]. For several fuels, Beyler [14] has determined and tabulated the product yields as a function of the oxygen and fuel supply ratio. For water

vapor and carbon dioxide, estimates could be adequately made from the known chemical composition of the fuel. But for carbon monoxide, the major toxic fire product for most common fuels, the experimental determination procedure described by Beyler [14] offers the only means for estimating CO in fire problems. Thus, estimates of CO are possible over a wide range of fire growth conditions, provided the fuel and oxygen supply rates can be determined. Since only limited material data exist, judgement must be used to extrapolate to other materials. Nevertheless, this approach might be perfectly valid in design situations where an evaluation of a specific material is not at issue.

3.3 Effect of Fire on the Surroundings

A primary effect of the fire on its surroundings is the heat transfer caused by the direct interaction of the flame and its plume with surfaces and objects. For fires along walls there are good results available to assess convective heat transfer [15], and a correlation has been developed to estimate the total heat flux distribution for flames of moderate size (< 2 m) [16]. For larger flames within the flame zone, radiation heat transfer is not generally predictable, but some limited data exist to show its magnitude. A similar state of knowledge exists for flames impacting ceilings; however, more work has gone into the study of this problem than for walls. Again, convective heat transfer is well predicted [17], and a more limited knowledge is available for the flame impingement region [18].

Very little general predictive ability for objects in fire plumes has been pursued, but to the extent that the velocity and temperature fields are

available, estimates of heat transfer to objects in these plumes can be made. In particular, a number of studies have been made to enable the prediction of the velocity and temperature distribution of a ceiling jet that arises due to the interaction of a fire plume with a ceiling. It should be mentioned here that the principle variables required to make these calculations of heat transfer are the energy release rate of the fire and geometric variables which describe the configuration.

An example of the use of ceiling jet research is in determining the response of alarm and suppression devices located in the jet. The standard, NFPA 72E on automatic fire detectors, contains supplementary information on how to determine the spacing of thermal detectors based on the rate of growth of a design fire, the ceiling height, and the response characteristics of the detector to temperature [19]. Much of the research that underlies this procedure was developed at Factory Mutual Research Corporation (FMRC), and is described in the Standard. This procedure has been further developed into a series of PC compatible computer codes (DETACT) for more general application [20]. A necessary ingredient of this procedure, is the availability of test data on the thermal response of the detector. Essentially the detector is approximated as a uniformly heated object in gas stream of known temperature and velocity. The overall convective heat transfer coefficient is determined from this test (commonly known as the "plunge test") and then related to the ceiling jet characteristics. This is an approximate method that has been shown to work, and refinements can even make it better. It is significant that it requires data for the detector or in general, the thermally responding device. The data are realizable from a test procedure, and are compatible

with an analytical procedure to make general predictions of performance under fire conditions.

3.4 Fire Conditions in a Room

I would now like to turn my attention to computer models that describe the conditions that arise in a room due to the presence of a fire. There are many computer codes available and I will not enumerate them all, but refer you to the citations given in References 1 and 2. They differ in approach. The field models attempt to represent all of the fire phenomena by solving the conservation equations. The zone models tie together homogeneous phenomenological regions and relationships which describe their interaction by globally applying the conservation laws to these regions. The current state of computers allows three dimensional solutions in the field models, and more than one room is possible. The zone models differ in scope and generality, with some including a limited amount of the known physics, or are restricted to a specific class of problems. Few of the room models address the effect of the surroundings on the fire, with many relying on a prescribed fire. Let us examine two classes of problems: fire in a closed room, and fire in a vented compartment. I will try to give some background and a measure of success and application.

3.4.1 Fire in a Closed Room

Fire conditions in a closed room can be solved by the zone modeling strategy to give the depth and properties of the hot upper layer formed by the

collected fire gases. Typical models consider no pressure rise for a room with a leak, which is characteristic of conventional rooms in buildings. It is possible to overcome this restriction. The basic theory was first put forth by Zukoski [21], and later a computer version was developed by Cooper [22] which has seen popular use. That computer model is known as ASET and is limited to just the closed room. This zone modeling approach has yielded good results in the prediction of the layer characteristics in time for smoldering fires [23], and for a variety of flaming conditions in complex closed configurations. In a series of experiments designed to test the approach, it was found that the smoke layer descent is predicted very well in time, but the temperature results are only approximately predicted since the actual thermal stratification is more gradual than the square-wave approximation of the zone model [24]. These experiments were done in a cubical room, 6 m on a side -- a large room. Bengston and Hagglund [25] applied their model to an entire building having a floor area of 1000 m^2 and a height of 9.5 m producing also good agreement between the model and measured results for the layer descent [25]. Nakamura [26], using a more sophisticated zone model than ASET, demonstrated good predictive ability for the layer temperature and descent rate for experiments conducted in a large exhibition hall with a domed roof -- 2000 m^2 of floor area and 19.2 m high. Thus, this approach appears quite valid regardless of the scale of the fire and the compartment. Of course, the fire source must be specified and is not influenced by the conditions in the compartment in any of these models.

Field models have also been applied to this problem with good results. The range of predicted variables is basically the same as those of the zone

models; however, they can not predict the degree of stratification. Cox et al. [27] show good results for temperature and carbon dioxide distributions in experiments in a six-bed hospital ward. Waters [28] has used the same model to evaluate particular fire safety issues in buildings under design. These included the issue of safe egress time due to a fire in a large airport terminal, and the effect of initial thermal stratification of a fire in an atrium space.

3.4.2 Vented Compartments

Field models do a good job at predicting the velocity and temperature distributions in compartments including the flow at door or window vents [29,30]. These verifications have been made for relatively small fires that only fill a small portion of the room.

The use of the zone model for vented compartments was made possible by the ability to predict the pressure-driven vent flows using a simple hydrostatic model with an orifice. We now have good confidence in this vent model. Recently, this model was proven to be very accurate for fire flows between two rooms with a fire room temperature as high as 1000 C [31]. In the application of this hydrostatic model to the zone modeling approach, the added assumption of uniform temperatures in the upper and lower layers is invoked. To the extent that these uniformities occur and to the extent that the zone model can predict the layer temperatures, the pressure-driven vent flows should be well predicted. Where flows across vents are due to instabilities or turbulent

diffusion, such as the flow through a single ceiling vent in a heated compartment, we have no generally accepted way to compute the flow.

A typical indication of the accuracy of the zone model capability has been reported by Mitler and Rockett for the Harvard Fire Code [32]. An improved version called FIRST has been developed for general use. In their comparisons with two simulated bedroom fires, they obtain good predictions for layer position, temperature and the primary combustion products (not CO), vent flow, and the burning rate of the fire. The model is also capable of predicting the surface temperature of a target and its ignition. It also can include thermal feedback effects to the fuel provided the fuel properties are appropriately defined, and a compatible model is supplied for the fuel package of interest. The Harvard model has probably accounted for the effect of the surroundings on the fuel as much or more than any other zone model. But the capability still needs to be improved in dealing with feedback effects on the fire and for the case of the fuel-rich fire.

The problem of a roof-vented compartment fire, with a sufficient vent below, was studied by Thomas and Hinkley nearly 25 years ago [33]. It was based on the zone modeling approach, and was intended for the sizing of roof vents in fire. The principles of that analytical method formed the basis for several European venting standards, and a modified version has now become the basis selecting the vent area in the standard, NFPA 204M [34]. A set of design fires, described in terms of their rate of growth, is provided. Other needed information is the height of the building and the configuration of the curtain boards. The vent area can be computed for a particular fire

condition, or selected period of effective operation. A similar analytical method has been included in another standard [35] which addresses the recommended mechanical exhaust capacity for smoke control in a multitiered open cell block. Thus, we see that some applications of the zone modeling approach are finding their way into standards of recommended design practice.

3.5 Fire Conditions in a Building

The zone modeling approach appears to be the only viable way to predict the conditions in a building due to fire. These conditions pertain to the motion of fire gases, their temperature and combustion product concentrations, and the speed at which spaces of the building fill with the gases. These computations require mini-computer capacity in the least. Also they would require judgement in the way a building geometry is approximated in terms of the necessary model input. All aspects of a building's rooms and vents would not be feasible to include.

A measure of the accuracy of zone models in predicting the fire conditions in more than one room has been described by Rockett, Morita and Cooper [36]. They examined data from a relatively small fire in a series of three rooms. The results for temperature and layer height are estimated quite well for each of the three rooms. Nakamura [26] and Tanaka [37] have demonstrated computations for multi-storied buildings of up to 10 stories and 50 rooms. Stairwells or vertical shafts are currently treated as tall rooms. We know this assumption is not satisfactory once the plume gases fill the cross section of the shaft, but we do not have a measure of its inaccuracy or an

alternative approach. A similar limitation applies to the motion of fire gases through corridors, since the concept of uniform filling from the top of the corridor is not compatible with our observations. This limitation will cause a discrepancy when the corridor smoke transit time is long compared to its filling time. Again we do not have a good measure of issue. While it is possible, the zone modeling applications to buildings have not incorporated the effects of the forced air heating and cooling system, nor have addressed the initial and ambient conditions that pertain to "stack" (buoyancy) or wind effects. Although small specified fires have been considered for the most part in these applications, it is possible to consider larger fires that become oxygen deficient [37]. Thus it is possible to predict conditions as a fire might spread from room to room, but we do not have good experimental data to support the assumptions needed here.

3.6 Effect of Fire on the Structure

Analytical methods for predicting the load bearing capacity of structural elements in a fire are based on the current structural design methods and the ability to predict the structural property data at high temperature. Much work has been done in this area, and sufficient property data exist to consider concrete, steel and even timber construction. A good discussion on the state of the art was recently prepared by Pettersson [38]. This approach considers a specified heating load to the structure, and proceeds to compute the temperature distribution, usually in two dimensions, over time by a finite-element method. This is primarily a heat conduction computation with the possibility of phase change modeled for some materials. Sufficient

confidence in this approach has led some European countries to accept a computation to predict the failure time of concrete or steel beam or column elements as exposed to a test fire, a time-temperature curve representative of a standard furnace test. I have been told that Sweden, Denmark and Norway have such provisions in their national fire safety codes, and others are considering similar adoptions.

In some of these applications, the fire heating load to the structure is computed from compartment fire models or correlations for fully developed fire conditions. These give the heating time-temperature curve in terms of the compartment size and thermal properties, vent area, and fuel load which is usually in based on data for wood cribs. Improvements are needed here. We need better and more complete ways to predict the post-flashover compartment thermal conditions for other fuel types and configurations. The thermal boundary conditions which express the transfer of energy between the fire and the structural element need more attention. And heating effects of fire plumes to structures need to be characterized. All of these issues fall on the side of the fire and combustion scientist; the structural engineering ability appears to be in good shape provided the heating conditions can be established.

3.7 Effect of Fire on People

A major requirement of the fire safety design of buildings is the safety of people. Their ability to safely egress the facility in a given period of time is essential. The fire behavior in a design calculation can determine

the critical times required for safe egress. Most current fire safety codes impose exit width requirements based on the type of facility and its expected population. Time for egress is not an explicit requirement. Based on studies of crowd movement in buildings and exit ways, correlations have been developed which allow the computation of the people movement speeds, the number of people per unit time, and the overall egress time of the building population. A review of these methods and the state of the art has been given by Kendik [39], and a book on the subject has been translated from the Russian literature [40]. Kendik points out that only the building codes in the Soviet Union require a mathematical proof of their exit width requirement. A recent edition of the NFPA Life Safety Code 101 provides information on alternative calculations for determining stair widths based on crowd egress time [42].

We are seeing more and more considerations of matching the hazard time of the fire with a computation of egress time for the design population of the facility. For example, the exit design of a large enclosed stadium with a capacity of 11,500 people was evaluated by computations of the smoke movement from a selected design fire and the traffic flow speeds of the spectators [42]. A formal adaptation of this process is currently under consideration in Japan as a Fire Safety Design Method to be used as an alternative to the Building Standard Law [43]. This design method addresses computations for smoke movement and people movement.

For the most part the egress models referred to above are independent of the effects of the fire on the people. A complete analysis must consider the effects of smoke on visibility; the impairment, toleration and lethality

caused by the fire and its products; and the behavior of people in a fire environment. We are limited in our ability to quantitatively address all these effects. Human tolerance limits are not precise, and our ability to convert these effects into mathematical models with a complete set of variables will always be imperfect. But for design or hazard analysis, it is possible to address some of these interactions. Methodology which is indicative of the state of the art has recently been published and is being evaluated by an interested group [44]. This approach, limited to residential single-family dwellings, contains computations on the fire; critical impairment to the people; and the motion of the people based on behavioral decisions, smoke conditions and a simple traffic flow model.

4. APPLICATIONS

The review presented above has been qualitative in that the specific level of the accuracy of the various methods must be assessed by an individual examination of the literature. Another measure of accuracy is the wide spread acceptance of an approach by the scientific developers, and its adoption by the engineers. I have tried to show some sense of that dimension. Many of the analytical methods are generic because of their wide use, but have been individualized in vehicles of execution -- mostly computer codes.

The application of these analytical methods for fire safety have ranged from assessing a particular feature of a new facility in the design stage, to assessing conditions in an existing structure. They have been used to justify alternatives to the specifications in building regulations, and have been even

included in standards as prescribed alternatives to traditional practices. I have tried to give some noteworthy examples above, but I am sure that they only represent a small proportion of the use of analytical methods by consultants, and the trend in their use has increased in recent years.

A more dramatic use of analytical method in fire is in the reconstruction of an accidental fire disaster. This is design analysis in reverse, in that it suggests what should have been done. Moreover, it provides a more quantitative basis for establishing remedial actions. The fact that regulations might have been violated before a fire disaster may have nothing to do with the consequences of the fire. There have been several fire reconstructions of real disasters -- some due to a formal investigation, others mostly due to litigation over damage claims. A recent analysis which used a very simple form of analytical relationships and computer models, but applied in a comprehensive way, was able to reconstruct the events of a fire growth in a hotel and its consequences [45]. The accuracy of the results appeared to be consistent with the events, but that is not as significant as its illustration of the ability to quantitatively analyze a complex sequence of fire growth.

5. FACTORS AFFECTING THE USE OF ANALYTICAL METHODS

I see three factors which are important to the use of analytical methods in fire safety.

First, the results from scientific research suitable for design application must be assembled into a logical description for ease in understanding and learning. This is an educational and technology transfer process. Because the field of fire protection engineering has relied on non-analytical techniques, the background required for these engineers to comprehend the analytical methods must be provided in their training and formal education. Text books are sorely needed. The use of user-friendly computer codes might tend to off-set the need for a complete understanding of the particular analysis, but there is a risk of their misuse. The user must have sufficient understanding to effectively question the computer answers, and to apply the computer code to problems within its valid scope.

Second, research must continue to fill the gaps of knowledge needed by analytical methods in a timely manner. If a method does not fulfil all of the expectations and needs of the designer due to limits in its scope, it could lose its appeal. This loss is not necessarily due to its lack of technical quality, but due to its completeness. Speedy and plentiful progress has been limited in developing the knowledge of fire safety by the complex nature of the fire problem, its dependence on the maturity and analytical state of the related scientific disciplines, and the lack of great attention to its research. Most of the analytical capability we see emerging has had its basis in fundamental research. That fundamental research has needed a luxury of deliberate study and evaluation to reach a sound conclusion. Patience is a necessity here. We have seen good progress over the last 25 years, but the most systematic and fruitful progress with benefit to design has come when a

number of researchers have focused on similar research issues with resources for long range studies.

Third, a good dialogue must exist between the researcher and the practitioner. Design problems must be identified and formulated by the fire safety engineer and official, and articulated effectively to the researcher. In many cases, the research developments have motivated progress in design applications. Fire researchers tend to pick problems of interesting scientific challenge and logical extension of existing research. Fire safety research needs more direction from the practicing community, especially by those you have gained an appreciation of analytical capabilities.

6. FUTURE PROSPECTS

Based on the recent interests in analytical methods in fire safety, we are likely to see their increasing use. The ability of accessing analytical methods by personal computers is accelerating their use. The research developments are not advancing as swiftly as this transfer process. This may ultimately disappoint some.

A computer format for the transfer of analytical methods may serve to cloud knowledge rather than transfer it. The issue of one method versus another will always be present, and standard computer benchmark codes will have to be rigorously developed to make these evaluations. The benchmark codes will have to be judged by scientific peer review.

Analytical methods will influence the way we test components for attributes of fire safety. Data for components will be needed in a form required by the mathematical model. The model itself will establish the form of the data. The more general the results, the more their use will become. Ultimately this will change the nature of our existing fire test methods, and influence the way we express our codes and standards. The feasibility of predicting the fire growth and the egress of people in a large building is possible. Its acceptance as a viable analytical method will alter the way accepted levels of fire safety are expressed. Analytical methods have now given us more information and more variables. Our criteria for safety must now be couched in these new terms. This will take continual discussion and reconciliation with current practices.

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The ability to predict aspects of fire and its impact on a building's structure, contents and people is discussed in terms of its application to safety design. It is presented from the perspective of how research has addressed the prediction of fire phenomena. A review of the state of the art on the capability for predicting the fire, its impact and response, is given. Examples are cited to illustrate the scope and accuracy of predictive methods and how they are being incorporated into some codes and standards.

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